STAR at RHIC

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Outline

1) Introduction

2) STAR Physics Program

- *Physics working group*
- *Upgrade/physics programs and **TOF***
- *Run plan for 2009 – 2013**

* As prepared in May 2008

3) Summary and Problems

Physics Goals at RHIC

RHIC

Au+Au, Cu+Cu,
d+Au, p+p
at
200 – 5 GeV

Polarized p+p
at
200 & 500 GeV

p+p, d+Au
pp2pp

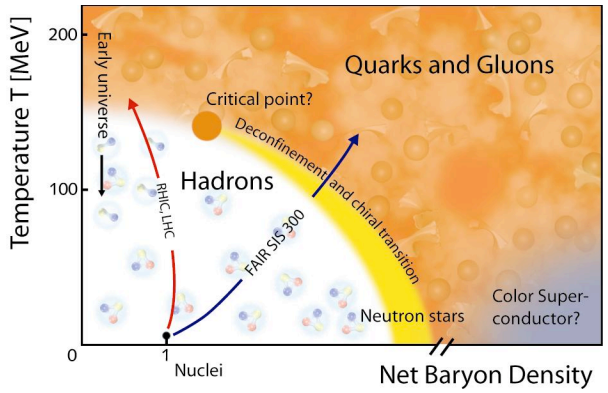
- Identify and study the property of matter (EOS) with partonic degrees of freedom.

- Explore the QCD phase diagram.

- Study the origin of spin in *p*.

- Investigate the physics at small-*x*, gluon-rich region.

STAR Physics Focus

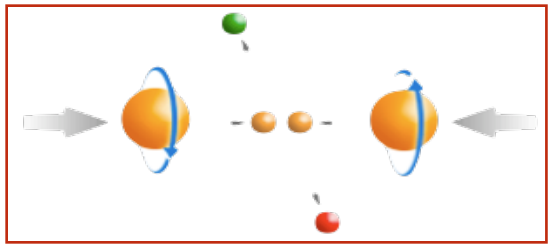


1) At 200 GeV top energy

- Study ***medium properties, EoS***
- pQCD in hot and dense medium

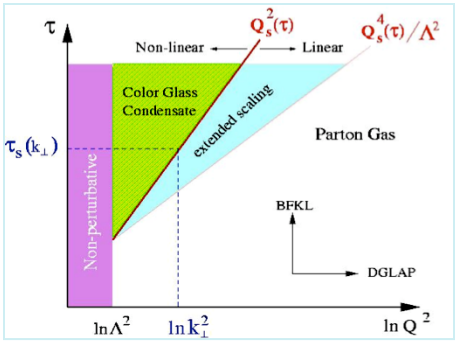
2) RHIC beam energy scan

- Search for ***critical point***
- Chiral symmetry restoration



Polarized spin program

- Study ***proton intrinsic properties***



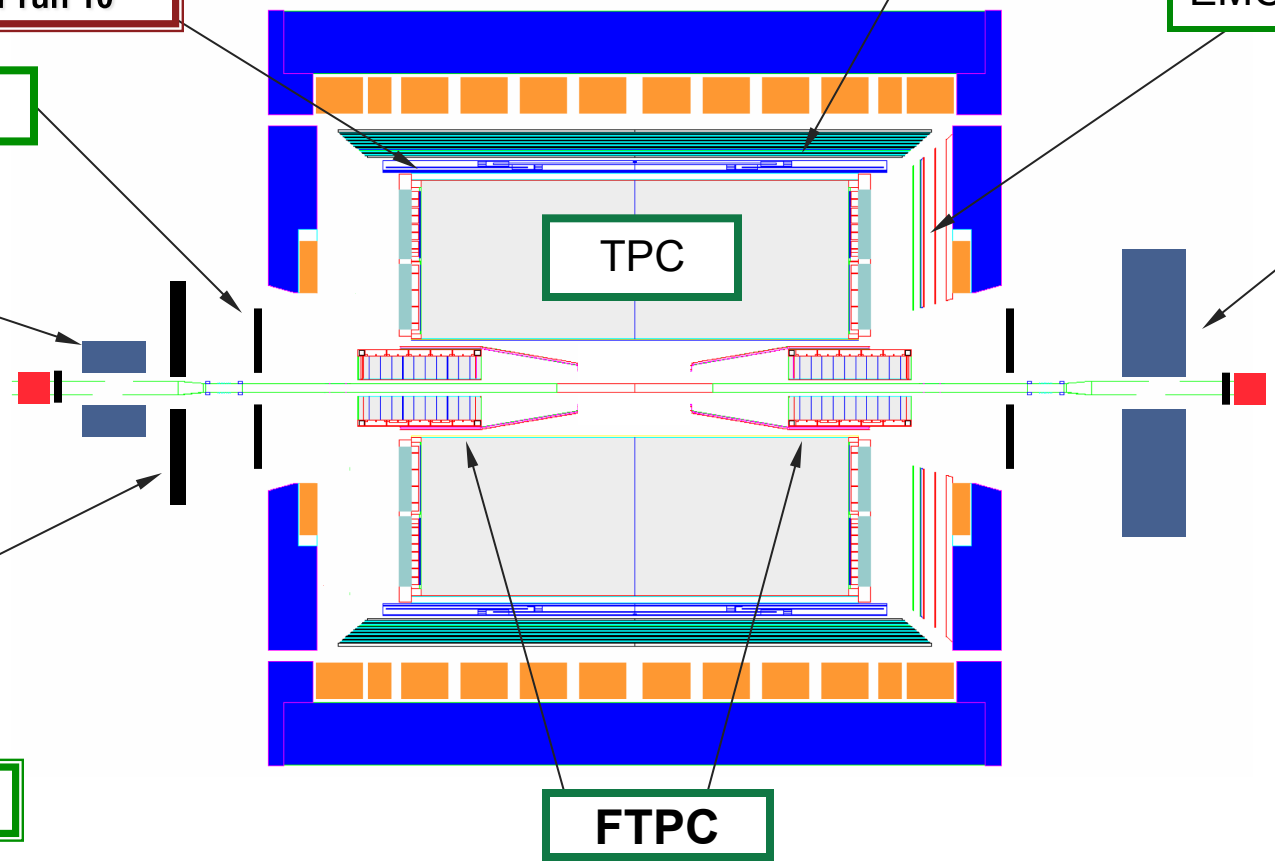
Forward program

- Study low-x properties, search for ***CGC***
- Study elastic (inelastic) processes (pp2pp)
- Investigate ***gluonic exchanges***

STAR Physics Working Groups

1) **Spin:**	*g* contribution to spin structure
2) **UPC:**	UPC, pp2pp
3) **Heavy Flavor:**	*c-, b*-quark hadrons
4) **Light Flavor Spectra:**	*u-, d-, s*-quark hadrons, di-leptons, photons
5) **Bulk Correlations:**	v_1, v_2, correlations/fluctuations
6) **Jet Correlations:**	high-p_T triggered correlations

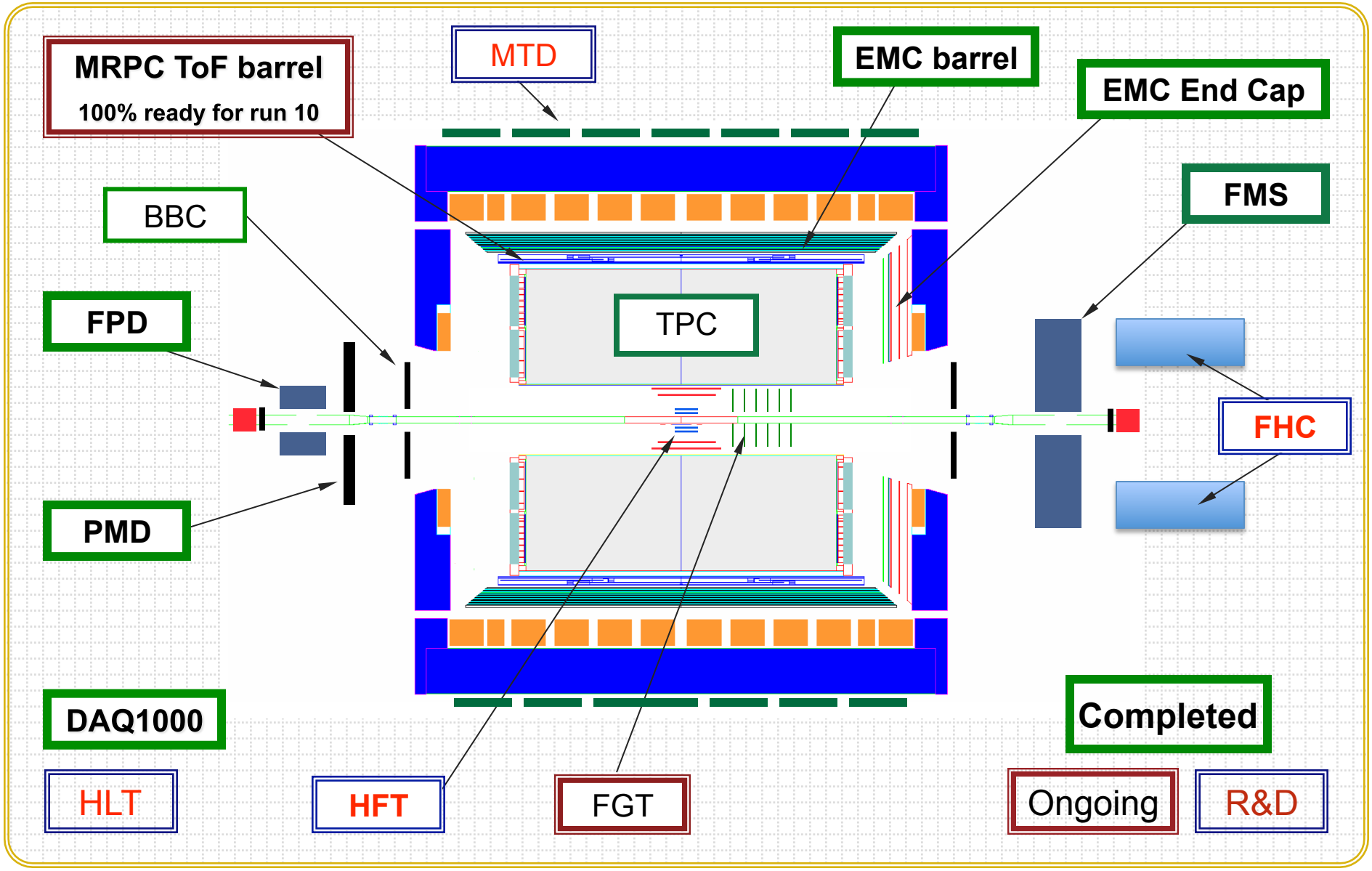
STAR Detector



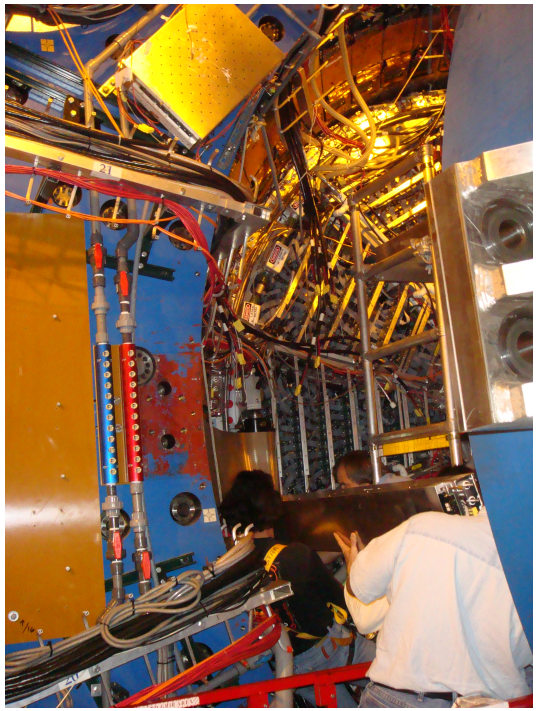
Full azimuthal particle identification!

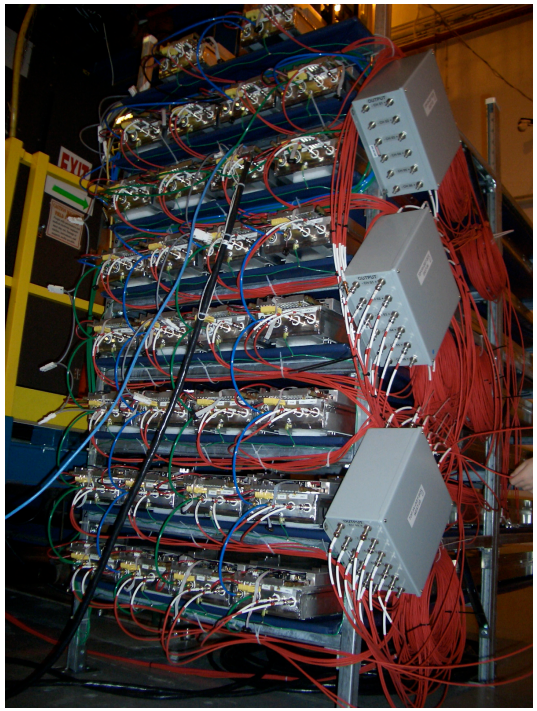
*γ, e, π, **ρ**, K, **K***, p, **φ**, Λ, Δ, Ξ, Ω, D, Λ_c, **J/ψ**, **Υ** …*

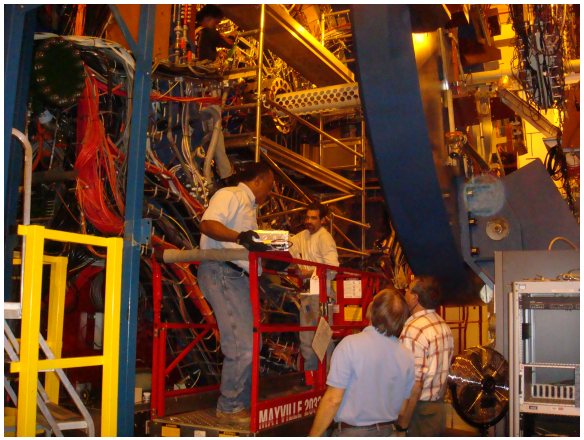
STAR Detector

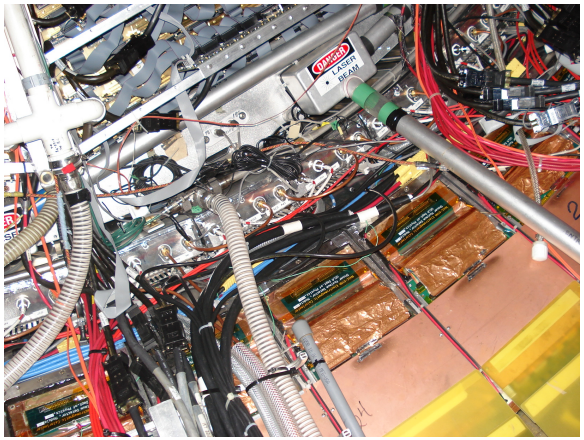


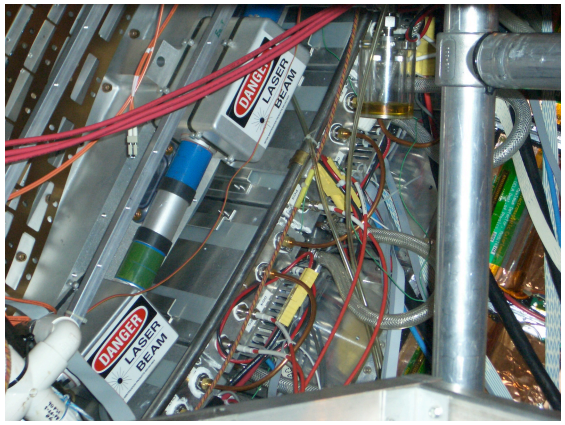
STAR ToF Installation (Fall 2008)





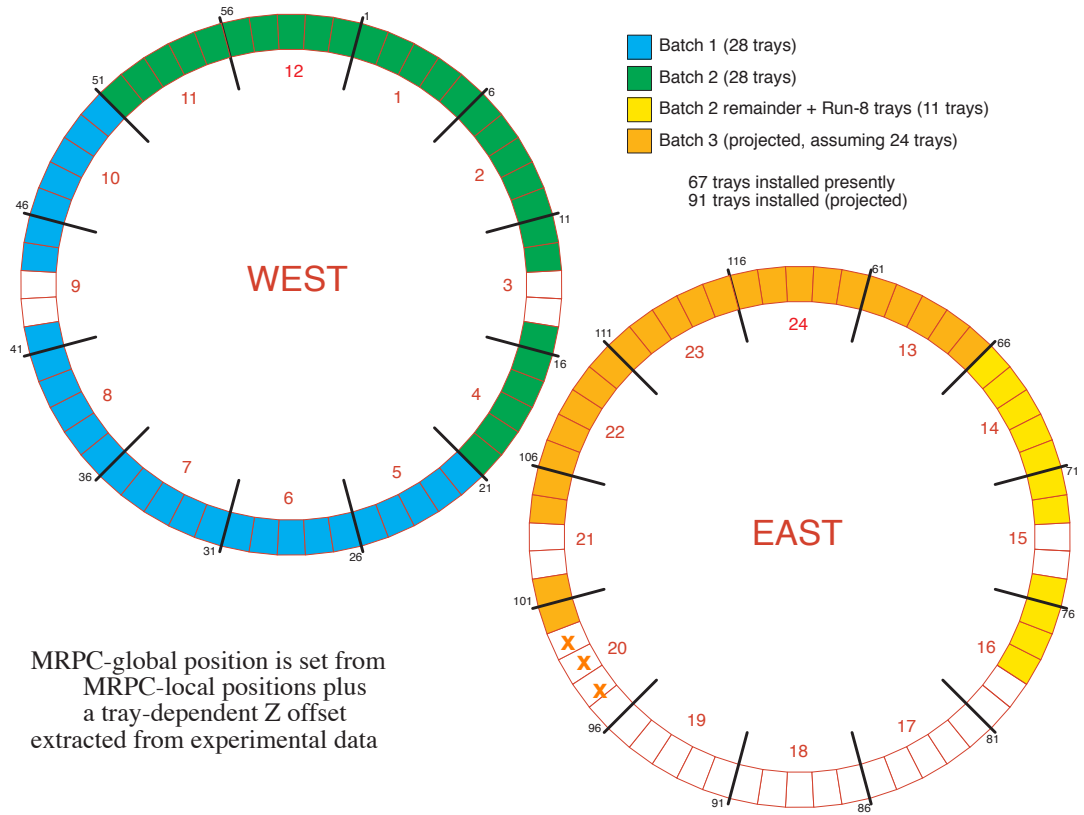






TOF Trays Installations

From W.J. Llope, *STAR ToF Software Review, Nov. 2008, BNL*



Dec. 2008: 94/120 installed
Will be completed in 2009

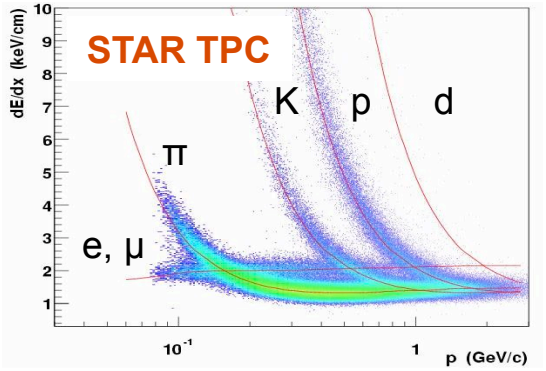
Ready for BES in the Fall of 2009 (Run10)

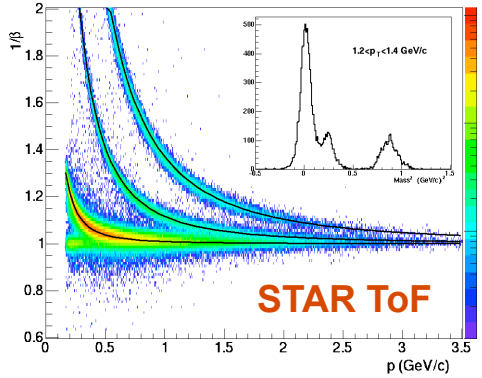
Installation team:
L. Ruan, M. Shao *et al.*
A team of software in place: X. Dong

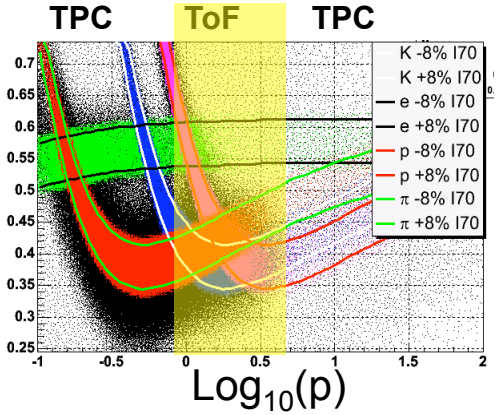
Physics case stronger:
MC simulations from IOPP, SINAP and USTC groups

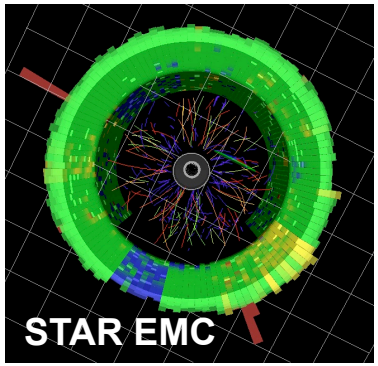
(1) Extend PID kinematic range, 2π; (2) PID multi-particle correlations
(3) Heavy quark (decays and correlations); (4) **Di-lepton program**

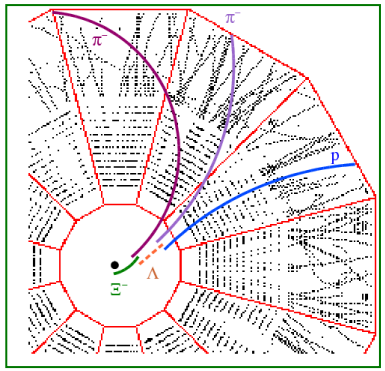
Particle Identification at STAR

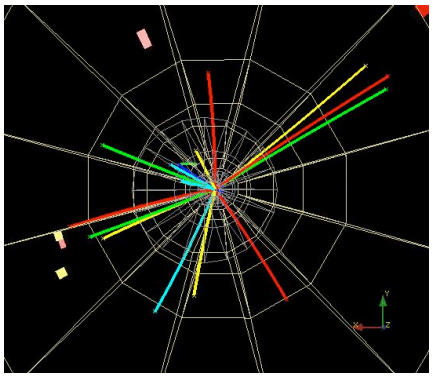


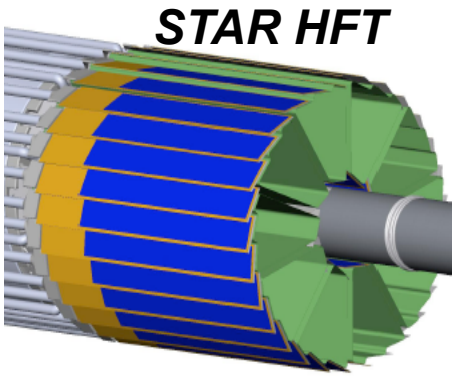








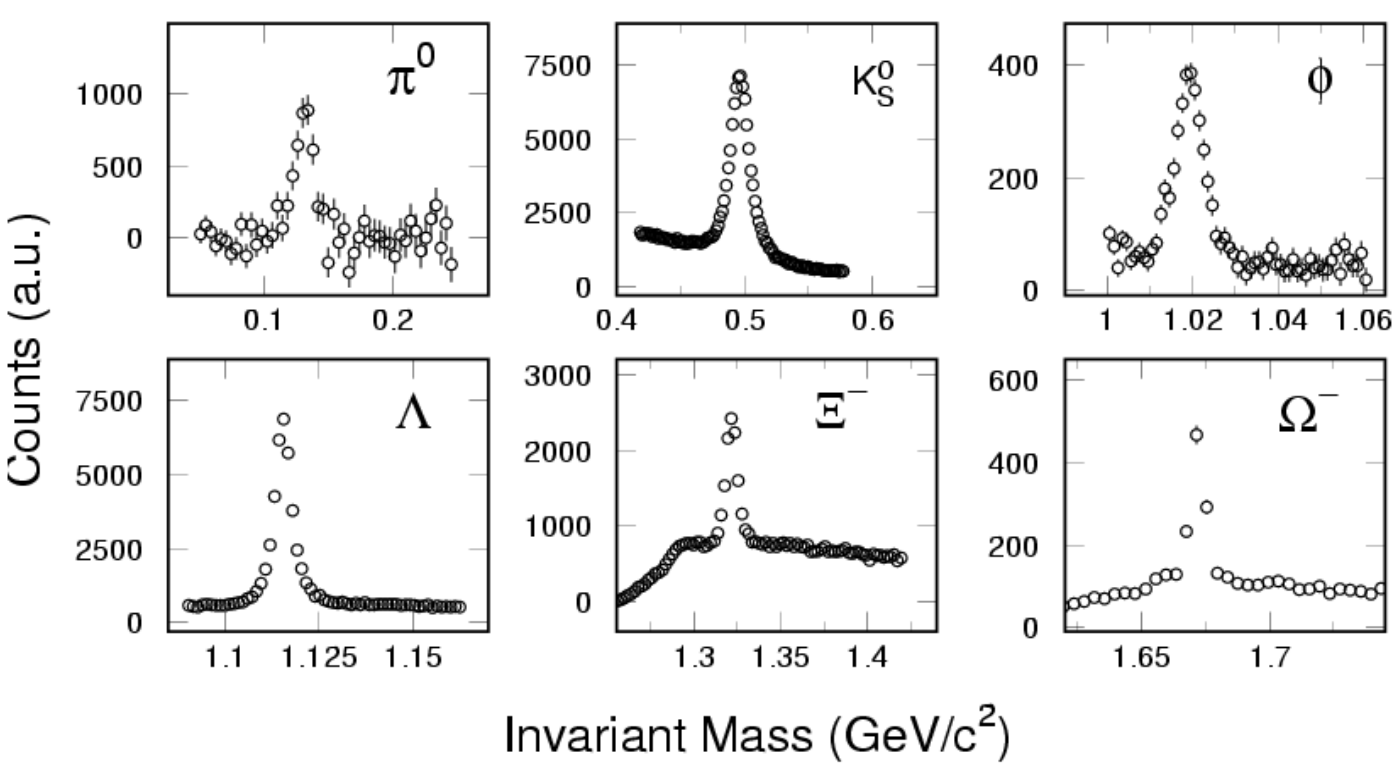


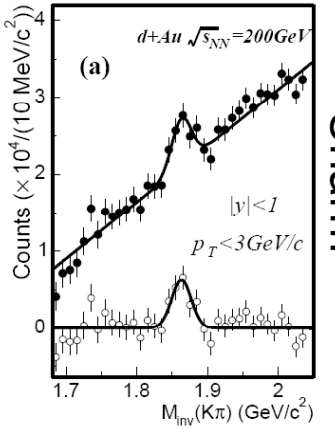


Neutral particles **Strange hyperons** **Jets** **Heavy Quark Hadrons**

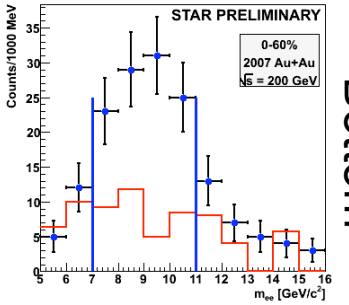
Multiple-fold correlations among the identified particles!

Particle Identification (ii)





Charm



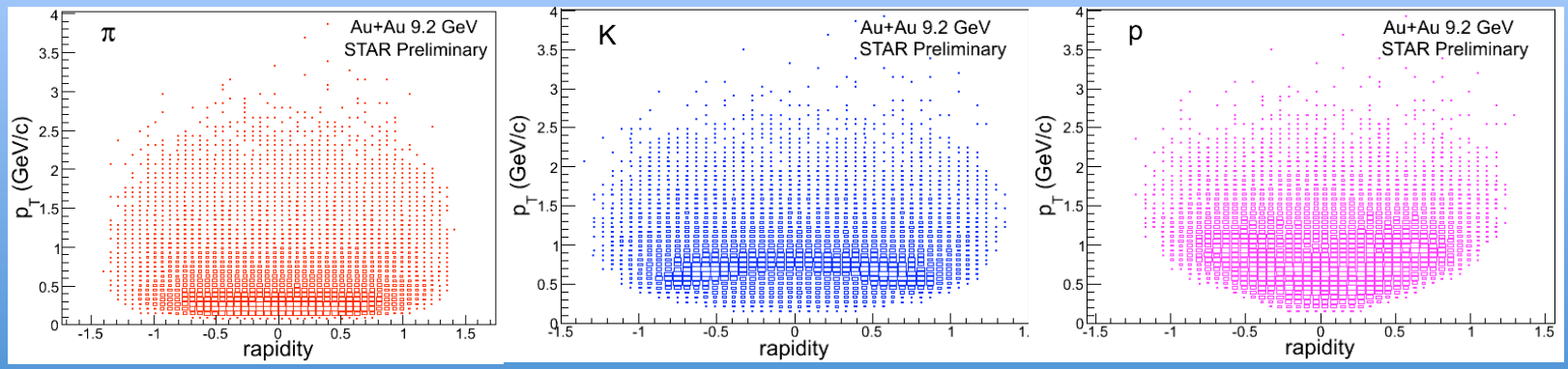
Bottom

Reconstruct particles in full azimuthal acceptance of STAR!

Collider Acceptance

Collider Mode STAR

$\sqrt{s_{NN}}$ = 9.2 GeV Au+Au Collisions at RHIC

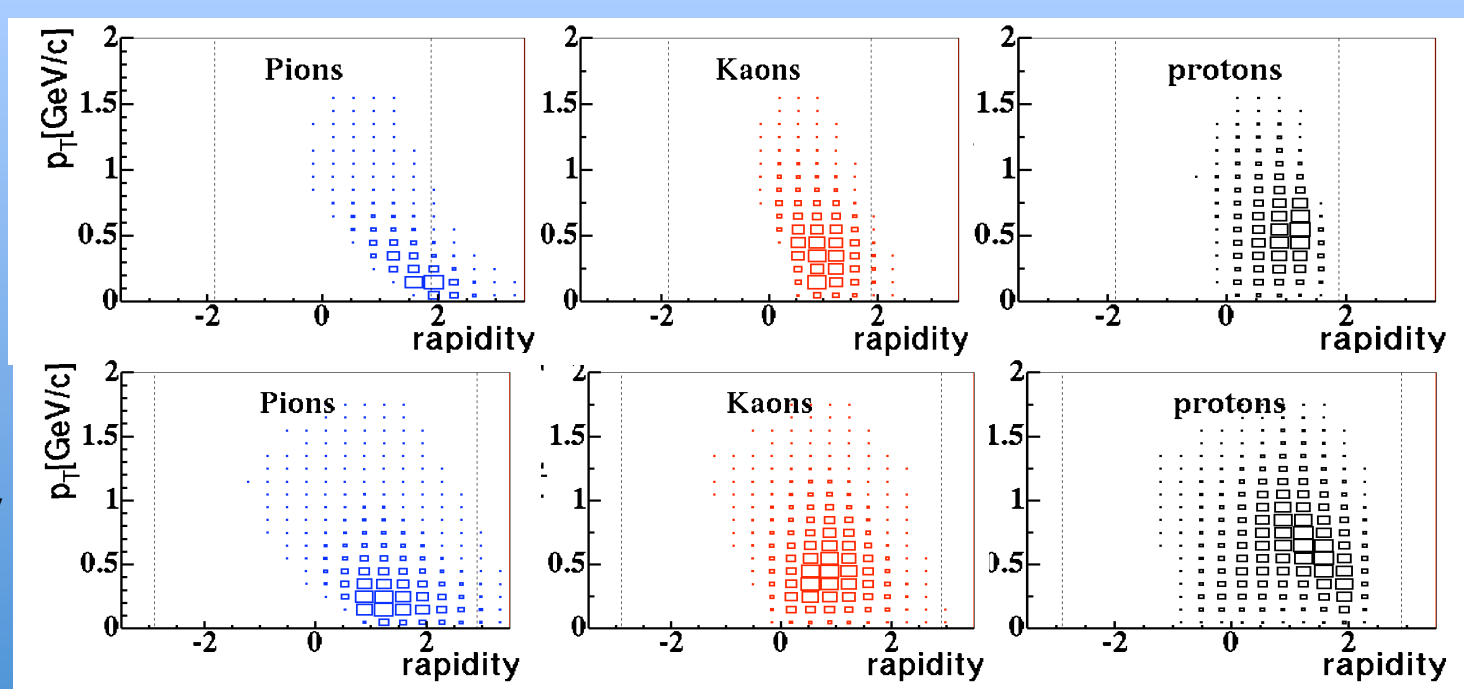


Fix-target Mode NA49

$\sqrt{s_{NN}}$

6 GeV

17 GeV



sQGP and the QCD Phase Diagram

In 200 GeV Au+Au collisions at RHIC, strongly interacting matter formed:

- **Jet energy loss: R_{AA}**
- **Strong collectivity: v_0, v_1, v_2**
- **Hadronization via coalescence: n_q-scaling**

Questions:

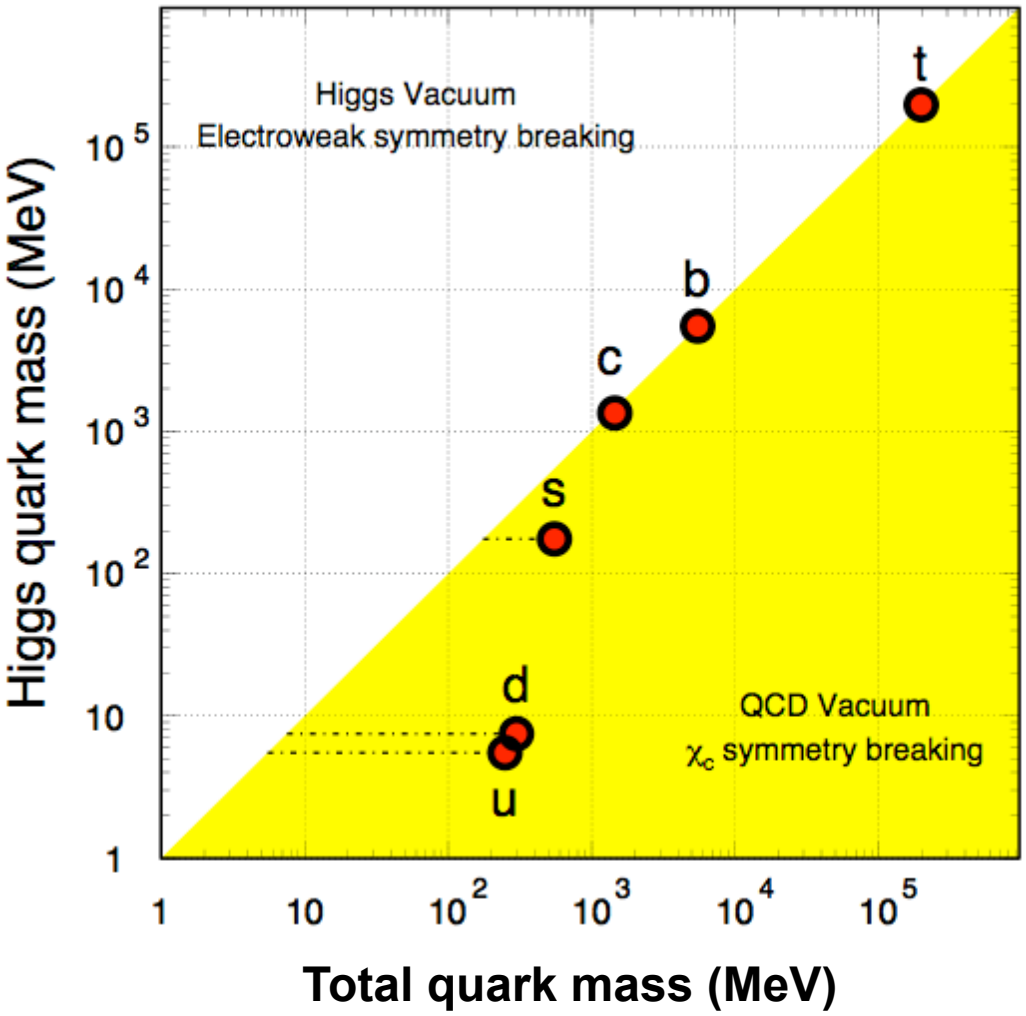
Is thermalization reached at RHIC?

- **Systematic analysis with dN/dp_T and dv_2/dp_T results…**
- ***Heavy quark measurements***

When (at which energy) does this transition happen?
What does the QCD phase diagram look like?

- ***RHIC Beam Energy Scan***

Quark Masses



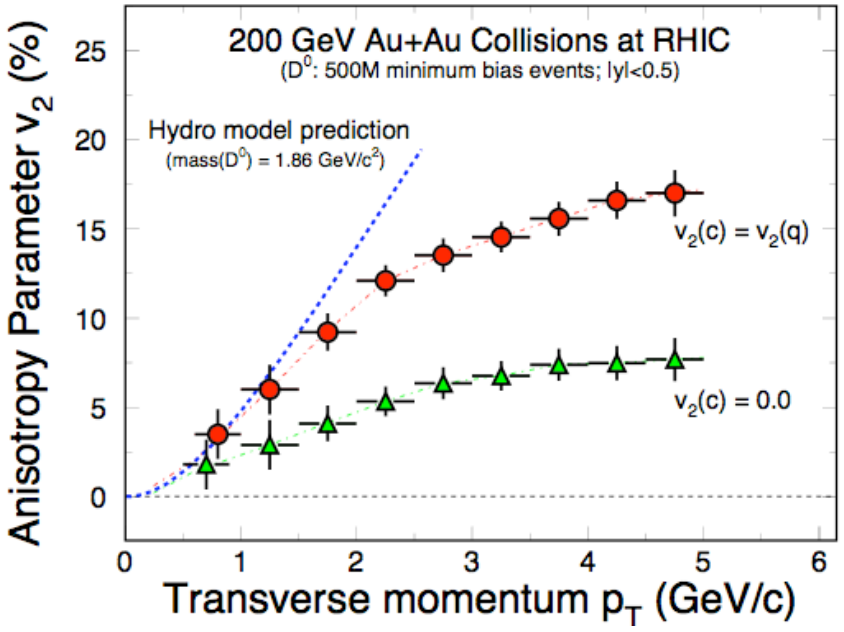
1) Higgs mass: electro-weak symmetry breaking. (current quark mass)
2) QCD mass: Chiral symmetry breaking. (constituent quark mass)

⇨ New mass scale compared to the excitation of the system.

⇨ Important tool for studying properties of the hot/dense medium at RHIC.

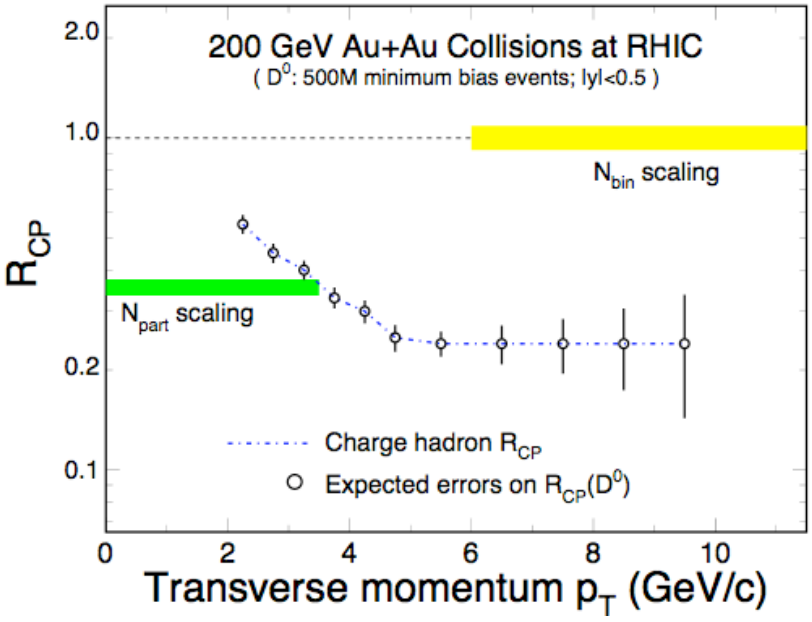
⇨ Test pQCD predictions at RHIC.

Charm Hadron v_2 and R_{AA}



- 200 GeV Au+Au m.b. collisions (500M events).
- Charm hadron collectivity ⇨ drag/diffusion constants ⇨

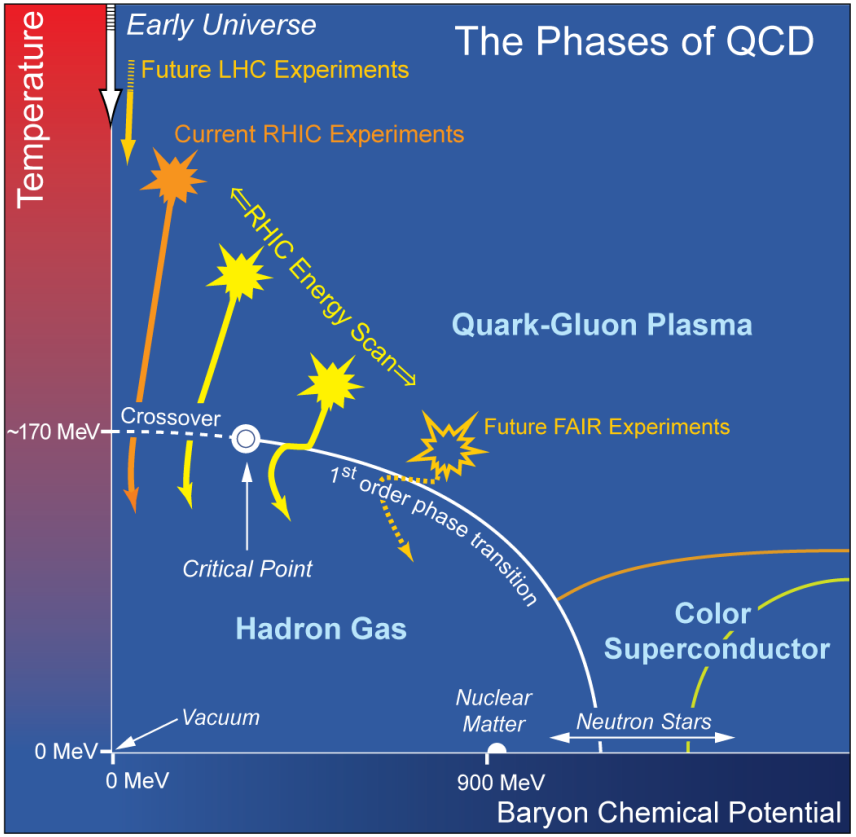
Medium properties!



- 200 GeV Au+Au m.b. collisions (|y|<0.5 500M events)
- Charm hadron R_{AA} ⇨

- Energy loss mechanism!
- QCD in dense medium!

The QCD Phase Diagram



STAR's plan:

run10: RHIC Beam Energy Scan
run11: Heavy Quark measurements

- LGT prediction on the transition temperature, T_c ~ 170 MeV.

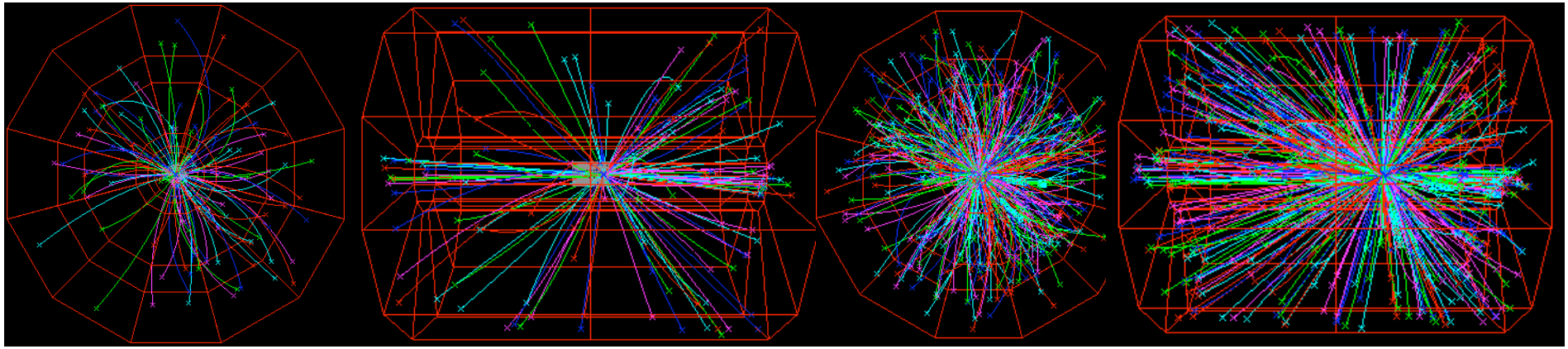
- LGT calculation, universality, and models point to the existence of the critical point on the QCD phase diagram* at finite baryon chemical potential.

- Experimental evidence for either the critical point or 1st order transition is important for our knowledge of the QCD phase diagram*.

*** Thermalization is assumed**

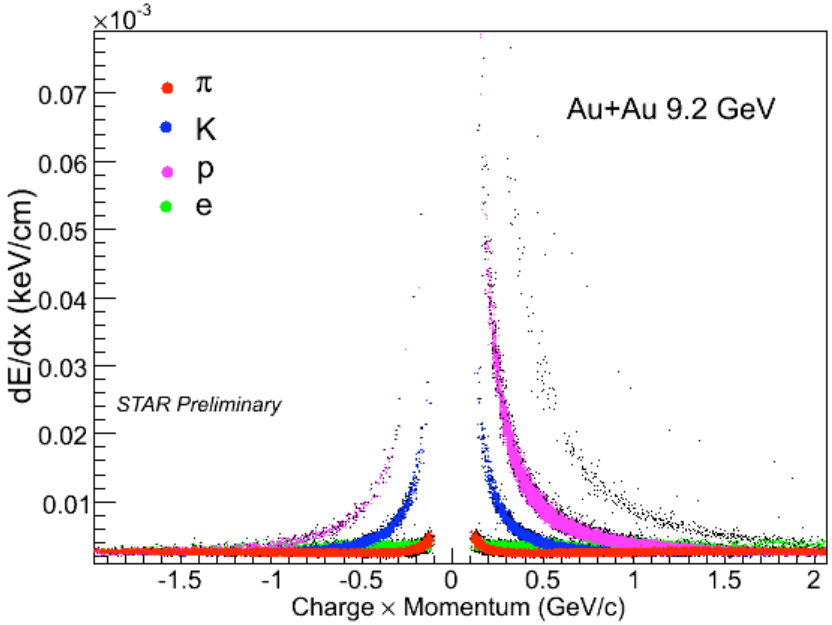
*Stephanov, Rajagopal, and Shuryak, PRL **81**, 4816(98)*
*Rajagopal, PR **D61**, 105017 (00)*
http://www.er.doe.gov/np/nsac/docs/Nuclear-Science.Low-Res.pdf

Au + Au Collisions at 9.2 GeV



1) **~ 3500 collisions collected**
2) **Determine Luminosity**
3) **STAR has preliminary results on:**

   Particle identification in TPC; charged multiplicity, π-π interferometry, particle spectra and ratios; v_1 and v_2



PID will be further significantly extended using full TOF. (Lokesh SQM08)

Run 9: 25 Cryo-week (scenario I)

STAR priorities for Runs 9 and 10:

(1) 200 GeV longitudinally polarized p+p - ***Δg(x)***

(2) Beam energy scan down to $\sqrt{s_{NN}}$ ~ 5-6 GeV
- Search for the QCD critical point

** C-AD transverse stochastic cooling test important!

Run	Energy (GeV)	System	Time	Goal
9	$\sqrt{s}$ = 200	$p_{\rightarrow}\ p_{\rightarrow}$	12 week	50 pb^{-1} P^4L 6.5 pb^{-1}
	$\sqrt{s}$ = 500	$p_{\uparrow}\ p_{\uparrow}$	2 week	Commissioning
	$\sqrt{s}$ = 200	$p_{\uparrow}\ p_{\uparrow}$	½ week	pp2pp
	** $\sqrt{s_{NN}}$ = 200	Au + Au	3 week	0.3B minbias, 0.5 nb^{-1}
	$\sqrt{s_{NN}}$ = 5	Au + Au	½ week*	Commisioning
10	$\sqrt{s_{NN}}$ = 39 – 6.1	Au + Au	14 week	1st energy scan
	$\sqrt{s_{NN}}$ = 5	Au + Au	1 week	Commisioning
	$\sqrt{s_{NN}}$ = 200	Au + Au	2 week	200M central
	$\sqrt{s_{NN}}$ = 200	Au + Au	1 week	50M central
	$\sqrt{s}$ = 200	$p_{\rightarrow}\ p_{\rightarrow}$	½ week	pp2pp
	$\sqrt{s}$ = 500 or 200	$p_{\uparrow}\ p_{\uparrow}$ or $p_{\rightarrow}\ p_{\rightarrow}$	4 ½ week	Spin studies

Runs 11 - 13 (30 cryo-week/yr)

Run	Energy (GeV)	System	Time	Goal	
11	$\sqrt{s}$ = 200	$p_\uparrow p_\uparrow$ or $p_\rightarrow p_\rightarrow$	6 week	20-30 pb^{-1}	
	$\sqrt{s}$ = 500	$p_\uparrow p_\uparrow$ or $p_\rightarrow p_\rightarrow$	15 week	150 pb^{-1}	FGT
	$\sqrt{s_{NN}}$ = 200	U + U	2 week	Commissioning	
12	$\sqrt{s_{NN}}$ = 200	Au + Au	12 week	0.5B minbias, 5 nb^{-1}	HFT
	$\sqrt{s_{NN}}$ = 39 - 5	Au + Au	13 week	2nd energy scan	
13	$\sqrt{s}$ = 200	$p_\uparrow p_\uparrow$ or $p_\rightarrow p_\rightarrow$	13 week	2B minbias, 100 pb^{-1}	
	$\sqrt{s}$ = 500	$p_\uparrow p_\uparrow$ or $p_\rightarrow p_\rightarrow$	12 week	300 pb^{-1}	

Run 11: (i) 1st measurement of flavor dependence of sea q/anti-q polarization in the proton at ***$\sqrt{s}$ = 500 GeV p+p collisions***

(ii) HFT engineering prototyping in ***$\sqrt{s_{NN}}$ = 200 GeV U+U collisions***

Run 12: ***Anticipating RHIC-II high luminosity***

(i) 1st HFT physics measurements of charm hadron $v_2(p_T)$ and $R_{CP}(p_T)$ in ***$\sqrt{s_{NN}}$ = 200 GeV Au+Au collisions***

(ii) Focused energy-scan in the search for the QCD critical point. Prior accelerator development is crucial at ***$\sqrt{s_{NN}}$ = 5-6 GeV***

(iii) gamma-jet and quarkonia states measurements

Run 13: (i) HFT physics reference measurement of charm hadron spectra in $\sqrt{s}$ = 200 GeV pp collisions; complete remaining ***$\sqrt{s}$ = 200 GeV*** spin milestones.

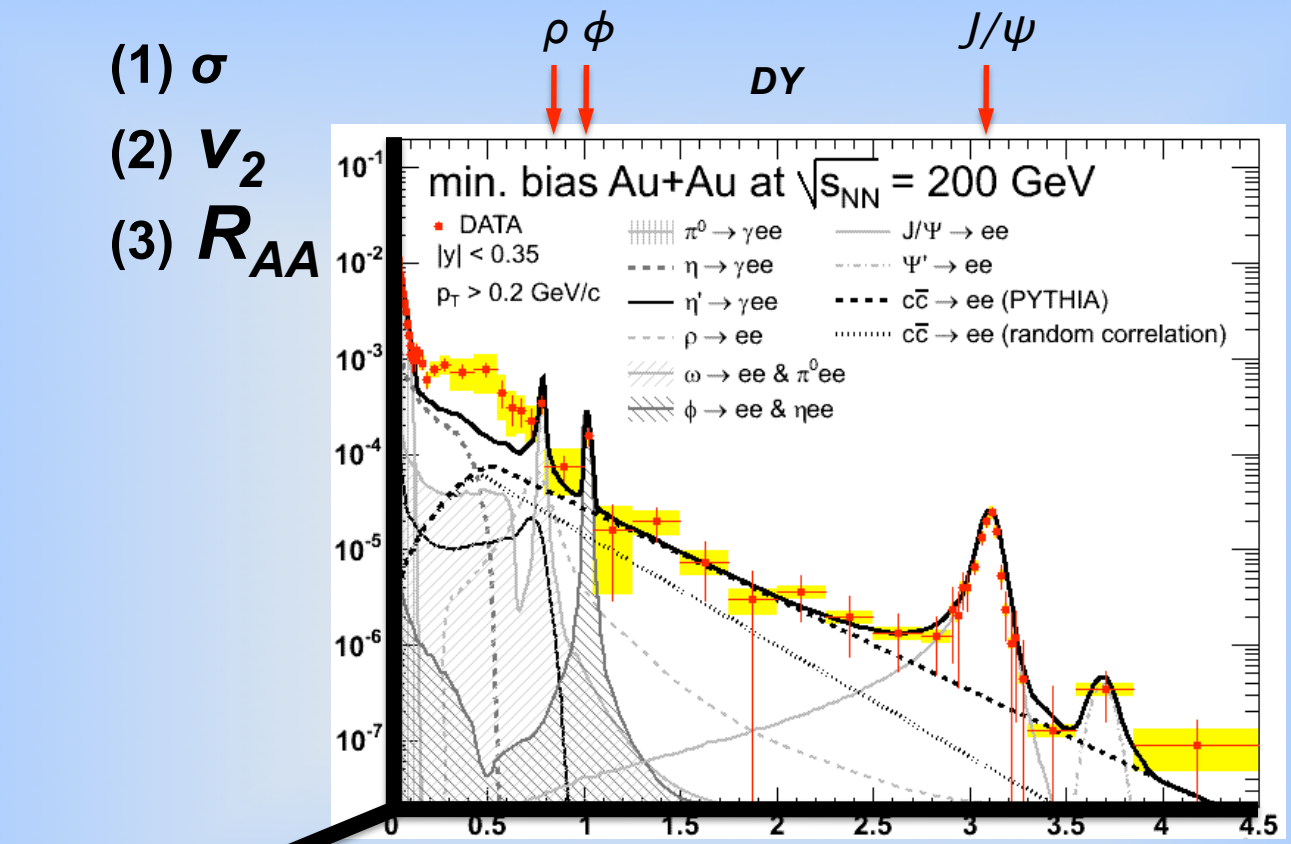
(ii) Measurement of the x dependence of W production at ***$\sqrt{s}$ = 500 GeV***

The di-Lepton Program at STAR

(1) σ

(2) v_2

(3) R_{AA}



✓ **Chiral Symmetry Restoration**

✓ **Direct Radiation from The Hot/Dense Medium**

Summary

STAR collaboration and its physics program are strong:

- **more** groups join in
- **best** positioned for Exploring the QCD phase diagram
- **best** equipped for Δg measurements at the highest energy polarized proton collider
- **Excellent** for precision measurements and **great** potential for new discoveries

Complementary to ALICE at LHC at higher energy
Complementary to CBM at FAIR at lower energy

Problems:

(1) Stable funding for upgrades and beam time
(2) Need more collaborators to work on detector

STAR Detectors: *Full 2π particle identification!*